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STRATEGIC MANAGEMENT OF INFORMATION TECHNOLOGY INVESTMENTS: AN OPTIONS PERSPECTIVE

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Abstract

In this paper we adopt financial options theory to guide decision making in the management of information technology investments. Information systems investment opportunities can provide firms with *real options* that can allow firms to exercise strategies for future growth or cost savings. These options, like call options on securities, represent real value to the firm and must be considered in the ex ante evaluation and justification of IT investment opportunities.

We illustrate the value of real IS investment options using an illustrative case example and develop implications of an options perspective on the strategic management process needed to realize value from information technology investments. This permits managers to better align the business, information technology and financial strategies of the firm.

1. Introduction

The management of the information technology (IT) investment process is an increasingly critical problem facing line and information systems (IS) managers. This is highlighted by the fact that IT investments are estimated to be 50% of all new capital investments made annually by major U.S. corporations [Kriebel, 1989]. The increasing number of competitive applications of information technology and its centrality to enabling a flexible and adaptive organization make the IS investment process a critical senior management concern. However, senior executives are increasingly frustrated by the difficulty of evaluating IT investment alternatives and effectively exploiting them to realize a positive return on investments [Kemerer and Sosa, 1989].

We believe much of the management frustration with the justification or realization of benefits from IS investments arises from the lack of an appropriate framework to conceptualize the IS investment process. In this paper we review existing methods of managing IS investments and propose a framework based on options theory to guide management decision making on information systems investments. We argue that strategic information systems (SIS) and infrastructure investments provide firms with managerial flexibility and real options to effectively respond to changing business environments, or achieve business growth and cost savings through the exercise of information processing based strategies. The options perspective augments current methods and provides a more rigorous and analytically sound approach to linking information technology investments to increasing the value of the firm.

In this paper we focus on the decision-making framework and the management processes required to effectively justify, select, and leverage information systems options to create business value. The paper is organized in six sections. Section 2 examines prior approaches to the evaluation and justification of information systems, illustrating their underlying assumptions and inherent difficulties. Section 3 defines options and identifies different categories of options associated with information technology investments. Section 4 a brief example of an options framework applied to an investment decision. Section 5 develops management process implications of an options perspective, and Section 6 outlines directions for future research.

2. The Information Technology Investment Process: A Review

The IT investment process is defined as the systematic identification, justification and leverage of information technology investment opportunities to create value for the firm. As Clemons [1991] notes significant progress has been made on identifying potential strategic applications [Rockart and Scott Morton 1984, Porter and Villars 1985], and on building and implementing systems. However, little formal progress has been made on determining which investments to undertake to maximize business value, or on managing the IS investment portfolio.

In a study of the investment management process in six different organizations, Weill and Olson (1989) found firms varied significantly in their practice of estimating returns from potential IT investments, and tracking expenditures and projects. Projects were justified in ways that include correct and incorrect approaches to capital investment decisions.

Incorrect approaches to valuation commonly undertaken to justify information systems investments are breakeven analysis, pay back period and internal rate of return. These approaches, illustrated in many standard finance textbooks, test if a project will give rise to a positive stream of benefits. The approaches are incorrect from the value maximization perspective because they are biased toward the project with the quickest pay back period rather than the one with the highest return on assets.

In contrast, a correct value maximizing approach such as discounted cash flow or net present value analysis enables managers to compare and select investment opportunities to maximize the return (Brealey and Myers, 1988). If the net present value is greater than zero, the firm should invest in the project. Larger net present value projects should take priority over smaller net present value projects. A NPV approach overcomes the bias toward projects that payoff more quickly.

However, Myers (1984) identifies four key difficulties in the application of NPV techniques for investment appraisal. These are the identification and estimation of future cash flows; identification and assessment of project impacts on the cash flows of other existing projects; and identification of the opportunity cost of capital accounting for its variation over time and incorrect addition of risk premiums to offset managerial optimism.

While these limitations are especially relevant to the appraisal of IS investments, they can be addressed through more careful implementation of the net present value calculation. In addition, managers can undertake sensitivity analyses to estimate project value under

different assumptions and scenarios. Indeed, a key benefit of traditional NPV calculations is that it permits a systematic analysis and comparison of alternative project values under different risk, cash flow, and business assumptions. By surfacing and tracking key underlying assumptions, managers can assess the validity of an investment strategy over time.

The key limitation of the traditional NPV project analysis is that it neither considers the value of managerial flexibility, nor the value of potential follow-on investments arising from the project. Indeed, many managers understand that the true value of information technology investments is not easily captured by NPV calculations. As Weill and Olson note, managers often turn to “soft” arguments to justify projects: arguing the projects have strategic potential to increase or maintain market share, to provide a basis for new sources of revenues, or to provide the flexibility to adapt to new business contingencies. Many researchers suggest that these opportunities be conceptualized as real options available to the firm (Kester 1984, Earl 1990, Clemons and Weber 1990).

We build on this prior work to illustrate the value of real IS investment options using a mini case study, and develop implications of an options perspective on the strategic management process needed to realize value from information investments. As discussed above, traditional approaches to IS investment appraisal can lead to investment decisions that do not maximize value. Incorrect approaches to valuation emphasize payback periods rather than value, and traditional NPV analysis does not account for managerial flexibility or growth options. This can result in non-value maximizing IS investments or non-investment in strategic or infrastructure IS projects. The firm can thus miss significant IS-based business opportunities.

The difficulties of appraising IS investments can also distort implementation of key business or IS strategies. Managers may treat IS projects as operating expenses to avoid justifying the project as a capital investment, thereby undermining the firm’s financial control systems. Projects may also be implemented in a piecemeal and non-optimal way due to justification difficulties. Finally, appraisal difficulties can lead to cross—functional conflict between IS and line managers, or between corporate and divisional IS functions. The framework discussed in this paper can ameliorate some of these difficulties.

3. Real Options and Business Value

In this section we identify and define various categories of real options, and illustrate how they create value to shareholders. In finance theory an option is a contract that gives its owner the right but not the obligation to buy or sell a specified amount of financial or real assets at a specified price by or on a specified date. There are two distinct types of financial options. A *call option* enables the owner to buy a specific amount of financial or real assets at a pre-specified exercise price at a specific time. A *put option* is the reverse, enabling the owner to sell a specific amount of financial or other assets at a predetermined price at a specific time.

Real options are analogous to financial options. Capital investments such as information technology can provide managers with *real options* or implicit contracts to exercise new IS based business strategies during the lifetime of a specific investment, or to expand or adapt existing projects and strategies to changing environmental contingencies. Alternatively, what is learned from an investment may be vital for a follow-on strategy. Thus, capital investments can provide real options for future growth or flexible adaptation that are of value to managers.

Kester (1984) provides a clear example of how shareholders and managers account for the value of real growth options available to the firm. He shows that for many growth firms, the actual capitalized market value of shares far exceeds the traditional net present value of projected earnings from existing investments. This difference in share value and the financial value of the firm's earnings potential represents the present value of growth options perceived by the firm's shareholders. These options arise from various assets that the firm currently owns or controls. Thus, shareholders not only value the direct stream of incremental revenues and cost savings, but also the growth options of follow-on investments and managerial flexibility enabled by current investments.

Brealey and Myers (1988), and others, identify a variety of generic real options associated with technology investments. These include the options for *follow-on investments*, *abandonment*, and the *option to wait and learn*.

Follow—on investment or expansion options: Today's investments may have features that enable a firm to exercise a specific strategy in the future. For example, investment in a data architecture or telecommunications network may provide the firm with an option but not an obligation to exercise a new product differentiation strategy that employs these

infrastructures. Such options can be likened to financial call options. Managers often recognize the availability of such opportunities, but their inability to estimate the value of these options forced them to rely on qualitative arguments about the investments' strategic value.

Abandonment or Salvage option: This option permits managers to put the investment to an alternate use. It provides a partial insurance against failure of a project or a strategy. For example acquiring equipment that conforms to de facto standards within the firm can allow managers to put the equipment to alternate uses, if the primary application is unsuccessful. This is analogous to acquiring a put option on a security.

Option to wait and learn: This option permits deferring an investment because the firm controls proprietary assets that allow it to wait for further information to reduce risks and costs. This is analogous to a call option.

Option pricing theory, which is concerned with the methods for valuing financial options, can be adapted to augment traditional net present value methods. The case study below provides an illustrative example of applying an options pricing theory to a specific IS investment decision. An IS investment perspective using option pricing theory is then developed to guide decision making in the evaluation, justification, and management of information technology investments.

4.0 Acquiring Real Options: An Illustrative Example

Healthways is a large for profit city hospital. Rising medical costs and increased competition from other care providers have made cost containment and improvements in the quality of care critical management priorities. Many managers felt the emerging technology of handheld computers showed significant promise in reducing costs and improving the quality of health care by providing nurses and physicians with timely information, and reducing the time, cost and nurses required to process, store, and maintain paper records.

A task force implemented to study the application of handheld computers at Healthways determined the hospital would have to undertake a variety of organizational and technology investments. Specifically, the project would require basic infrastructure investments in a new data architecture and a local area network as a platform for the handheld computing applications. Handheld computers and application programming would then be required. Finally the organization would have to train nurses to use the technology.

The task force then undertook a net present value analysis of the project to determine if they should commit resources to the project. The basic steps of the appraisal are discussed below.

4.1 Traditional Net Present Value Estimate of the Project

Step 1: Estimating Project Costs

The managers first estimated the project costs. The data architecture and LAN investments were estimated to cost \$1 million¹ to implement. Handheld computers and application programming was estimated to cost \$2.5 million. Training and implementation costs were estimated at \$500,000. Hence the estimate of the total initial investment I_0 was \$4 million.

Step 2: Identifying Project Risks

Next, the task force identified various risks associated with the project, to provide guidelines for estimating the cost of capital and identifying issues that impact the likely benefit streams from the investment. The managers identified a variety of risks, broadly categorized as *technical* and *organizational* risks. Technical risks were associated with the design, technical implementation and operation of an integrated information system. These include risks associated with implementing the key system components: the data architecture, the local area network, and implementing handheld computers in a hospital setting. Handheld computers were a new technology and relatively untested in hospital settings. In addition, there were technical risks associated with successfully integrating the system components and managing a multivendor environment.

The managers also perceived a variety of organizational risks. These include potential difficulties in nurse and physician acceptance, training and in use of the new devices in the hospital. More importantly, there was uncertainty about the outcome of ongoing contract negotiations with the nurses' union. The terms under which it would accept changes in nurse responsibilities and roles arising from the implementation of this new technology were not yet known. The new contract would become more certain within one year.

Step 3: Estimating Cash Flows under different scenarios.

The managers then developed a series of likely outcome scenarios for the project. Various scenarios were developed with different assumptions. Based on an assessment of these assumptions the task force then determined that there would be two likely outcomes: the optimistic and pessimistic scenarios.

In the optimistic scenario the different technologies would be successfully integrated into a system in a timely way without significant delay, and the technology would require low maintenance. In addition, the nurses would accept contract and work changes on generally favorable terms with the requirements of this system. Finally most of the potential savings from reduced paper processing would be realized. The managers felt there was a forty percent probability of this outcome. In this scenario \$1.8 million in annual savings to perpetuity would be realized, beginning three years from now.

In the pessimistic case scenario there would be higher technology implementation and maintenance costs, delays in implementation, and fewer savings than originally anticipated. In addition the nurses would accept a contract less favorable to the project. This scenario was assigned a sixty percent probability of occurrence. In this case only \$600,000 in annual savings to perpetuity would be realized.

Step 4: Estimating the Cost of Capital

To complete the net present value analysis the managers had to estimate the appropriate cost of capital. Some managers felt it should be set at the company cost of capital of 15%. However, other managers felt that the current company cost of capital did not reflect the true risk of the project. Unlike prior technology investments, this project had higher technological and organizational risks. They were especially concerned with the likelihood of successfully integrating different types of technology, as well as utilization and acceptance by nurses and physicians. Given these risks, the cost of capital was estimated at 20% for the project. This was more representative of the cost of capital to companies that sold or managed turnkey hospital information systems.

Step 5: Estimating Traditional Net Present Value

The present value can be derived using the standard present value formula. The present value of the optimistic scenario is \$6.25 million. The present value of the pessimistic scenario is \$2.083 million.

The expected present value of the project is:

$$E(PV) = (6.25)*0.4 + (2.083)*0.6 = \$3.75 \text{ million.}$$

Hence the net present value of the project is:

$$NPV = E(PV) - I_0 = \$3,750,000 - \$4,000,000 = -\$250,000$$

Step 6: Conclusions from Net Present Value Analysis

Based on the negative net present value the project should not be authorized. As the task force reexamined its estimation and assumptions underlying the project, they realized that the major sources of uncertainty were tied to the nurses' acceptance of the project and to technical integration issues. In addition, most managers still felt that handheld computers would become widely adopted in many hospitals. How could managers at Healthways resolve this uncertainty and position the hospital to effectively take advantage of this technology?

4.2 Acquiring an Option on the Handheld Computers Application.

The task force managers identified another investment opportunity available to Healthways. They could undertake a pilot project that implemented the local area network and most of the data architecture. The pilot project would also undertake a limited test of the handheld computer. After a year the results of the nurses' contract and the pilot program could be evaluated. If favorable, Healthways could expand the project to full scale implementation. This strategy would enable managers to resolve some of the uncertainty associated with the project but also position the hospital to quickly take advantage of the opportunity.

But what was the worth of the pilot project? As the pilot project would not have positive cash flows its net present value was clearly negative. However, this alternate investment opportunity can be viewed as acquiring a "real option" that positions Healthways to quickly take advantage of favorable changes in technology and nurses' contract. The real option

provides the firm the opportunity but not the obligation to further invest in handheld computers a year from now.

The binomial option pricing model can be applied to evaluate the value of this option. This is illustrated below.

Step 1: Estimation of Project Costs

The pilot program was estimated to require an initial investment I_p of \$1.1 million. This includes most of the data architecture, LAN and a pilot test of the handheld computers in a limited setting. To expand the project a year from now would require a further \$3.2 million. This is analogous to the exercise price of the real option, K .

Step 2: Defining the Option

Investing in the pilot project can be likened to acquiring a single period option on the handheld computer project. From their previous net present value calculation the present value of the handheld computer project is $PV = \$3.75$ million. One year from now, when the pilot project is complete, the managers will have enough additional information to know if the outcome will be the optimistic or the pessimistic scenario. If the outcome of the pilot project suggests an optimistic scenario, the managers are likely to continue the project to take advantage of the optimistic outcome. Otherwise the managers can choose not to invest given the likelihood of a pessimistic outcome. At this decision point there are two possible expected outcomes for project value: \$7.5 million (optimistic) or \$2.5 million (pessimistic).

We now determine the value of this real option from the pilot project. To do this we need to introduce the notion of a "twin security" S in the stock market that has the same risk characteristics of the original project and fluctuates in value identically with the original project value. By using this notion we can directly apply the Cox-Rubinstein binomial option pricing method² for estimating the value of this option. Investing in the pilot project is analogous to buying a call option on the twin security. If the investment costs I_p for the pilot project exceed the call value for the twin security, managers should not invest in this opportunity.

Specifically the initial value of the twin security, S , must equal the expected present value $E(PV)$ of the original project, i.e., \$3.75 million. In one year the value of the security will be $u \cdot S = \$7.5$ million or $d \cdot S = \$2.5$ million, which makes $u = 2.0$ and $d = 0.67$.

We denote the present value of the call option on this twin security as C . After one year we know that the value of the option is either:

$$C_u = \max[0, uS - K] = \$4.3\text{m} \quad \text{or}$$

$$C_d = \max[0, dS - K] = \$0.$$

Step 3: Estimate the Option Value

The Cox—Rubinstein³ formula (also in Appendix 1) was then applied to estimate the option value. The riskless rate of return was 5%. Hence $r=1.05$.

$$C = \{ C_u[(r-d)/(u-d)] + C_d[(u-r)/(u-d)] \} / r$$

$$C = \$1,177,391$$

Step 4: Investment Decision

The estimate for the present call value, $C = \$1.18\text{m}$, exceeds the present value of the investment $I_p = 1.1\text{m}$. Hence, restructuring the original project into a pilot project as a “real option” for full scale implementation of handheld computers is of positive value to the firm. Thus, the firm should acquire the option.

Step 5: Justification

The traditional IS planning and appraisal program did not differentiate between sources of risks in the project. Risk can arise from inherent market and technological uncertainties, or through attributable factors that can be addressed by data collection and testing using a pilot study. In the hand-held computer case the pilot project creates an option value by enabling managers to resolve and reduce downside risks such as the union contract, and technical uncertainties about the network and data architectures.

5.0 Managing the IS Investment Process: An Options Perspective

In this section we develop five implications for IS management that arise from the availability of real IS options.

Redesign Strategic IS Planning to Identify Real IS options

Business and information systems planning should be altered to identify and account for real IS options. Options provide managers a means to position assets to take advantage of business uncertainties. To identify real options, managers must systematically examine key areas of business uncertainty to determine if IS investments provide real options for business growth or security against downside risks from market and environmental changes. Real options arising from technological features can also be valuable to IS managers in positioning the IS function and managing risks in relation to both the information technology marketplace and the firm's internal market for information systems and services.

Evaluate Project and Option Values: Clarify Assumptions

Information systems project opportunities must be appraised to determine if they create shareholder value. Where the investment is the acquisition of a real option, or has associated follow-on, abandonment, or deferral real options, the net present value analysis must be augmented by applying option pricing techniques, and adding the option value to the net present value.

The quantification of information systems investment values can still be difficult to operationalize. However, the key benefit of net present value and options approaches is that they systematize the process for examining how IS investments creates value to the firm. The process can also surface assumptions underlying a particular project outcome. The decision to invest should not be based solely on a positive net present value adjusted for any options. As Myers (1984) notes, smart managers do not accept positive or negative NPVs "unless they can explain them." Thus, managers must explain the sources of the value, by showing how the project disturbs the short term competitive equilibrium to give higher profits, or how it adequately hedges against environmental risks.

Kester (1984) identifies key factors that affect the value of real IS options. For follow—on options, or deferred—investment options, the option value increases with the time to expiration. This is because the longer the time period, the greater the likelihood of changes in the environment that make the option valuable. Thus managers must consider the durability of specific IS options.

If two projects have the same NPV, and can be deferred for the same amount of time, the project with the higher risk will have greater option value. For the higher risk project the net present value in case of success is significantly greater than for the project with lower risk. Losses can be cut by not exercising the option if the environment makes the project unfavorable.

Higher interest rates can also favor investment in real options over those IS projects with immediate cash flows. First, the higher interest rates will depress the value of immediate cash flows, while reducing present value of future capital required to exercise an option. Hence under rising interest rates or more in more turbulent business environments, investment in real IS options becomes increasingly attractive.

Proprietary options that arise from specialized skills, information or assets such as patents available only to the firm can be more valuable than common industry wide options, as their exercise may be deferred for a longer time before expiration.

The use of financial analysis to surface and track key assumptions, helps managers assess the validity of investment strategies. This process is vital for ensuring “fit” between the selection of investments and the firm’s internal resources or business environment. Henderson and Venkatraman [1990] highlight the criticality of aligning business and IS strategies and capabilities to effectively leverage IS opportunities.

Acquiring Real Options Requires Investment in Real Capabilities

The owner of a financial option has well specified rights and mechanisms available to exercise the option or sell it to someone else who can exercise the option. In contrast, “real options” generally require unique configurations of resources and competencies to exercise them, and are difficult to trade. Hence, real options are a real capability to exercise a growth or adaptive strategy. In addition to investment in information technology a real IS option includes the acquisition of rights or control over a specific bundle of distinctive competencies and resources. These are required to translate the options into cash flows through exercising projects. Thus an IS investment provides a real option to the extent that the auxiliary resources necessary to exercise the option are available to the firm.

This is a major difference between financial and real options. While an options perspective may be used for a conceptual justification of an IS project, the real option must reflect a real capability of the firm to exercise the option. Hence the management process must carefully

assess proposals for acquiring real options from the perspective of organizational capabilities.

Implement an Information Systems Portfolio Management Strategy

Since the execution of the real option is a process and not an event, there are important implications for the design of a control system. To take advantage of real options, managers must implement a strategy to manage the IS investment portfolio. This requires a system for constantly evaluating the status of the portfolio's investments.

Real options require a management control system for tracking changes in the environment to determine if the options should be exercised, discarded, or maintained. When environmental changes favor exercising an option, new resources should be allocated to its implementation. However, if an option expires, any resources allocated toward its maintenance must then be redirected to other projects. The management strategy should ensure the availability of competencies and resources to exercise an option.

Organization to Manage Investment Interdependencies

Follow-on and abandonment options arise due to interdependencies between current investments and potential future investments. For example, the decision to adopt a standard technology may create an abandonment option to the extent the failure of the project still results in an infrastructure that enables flexibility e.g a data architecture enables implementation of an alternate project. How should the information systems investment process be organized to identify and take advantage of these options? What are the characteristics of and incentive systems that effectively promotes rational investments in IT infrastructures.

Two possible models seem viable. The first model involves a centralized fund that pays for all such investments. The alternative provides an investment credit process that ensures each business executive will augment their performance through useful infrastructure investments. In fact variations of each appear to be in place. The former reflects a centralized IS organization and allocation process, while the latter reflects a decentralized coordination approach. Under either scenario the management process must identify, coordinate, facilitate and monitor these investments.

6.0 Conclusions and Future Research

The options perspective outlined in this paper is a critical first step in establishing a clear linkage between many categories of IS investments and business value. This is necessary to effectively align the business and IS strategies with the financial strategy and the firm's objectives to maximize shareholder value. While option values may be difficult to quantify in certain cases, undertaking an investment analysis using sound financial principles will help managers surface assumptions about the project and focus understanding on those factors that affect the value of the project. This will enable more effective management of IS investments.

Many areas of research remain to fully incorporate an options perspective in the management of IS investments. First, process techniques for incorporating an options perspective in the strategic planning need further development. Second, IS investments must be systematically classified and linkage between these IS classifications and real options. This will identify categories of IS investment decisions common to most firms that need to be analyzed from an options perspective. Third, decision support tools and valuation techniques for real options including complex or cascading options need to be further developed. This will assist managers in the evaluation of project value and investment alternatives. Fourth, new techniques that emphasize the economic benefits from managerial flexibility, in addition to productivity gains, must be developed to evaluate the performance of the IS portfolio. Finally, further research is required on how investment review and resource allocation authority should be distributed for different categories of IS investments.

Appendix 1

Estimating Option Values using the Cox—Rubinstein Binomial Option Pricing Model.

In this section we illustrate the Cox and Rubinstein binomial option pricing technique for the estimation of single stage investment options. Cox and Rubinstein specify an exact option pricing formula for financial assets over a single period. Let us imagine a stock or financial asset of current value or price S . After one period the stock can increase to a value uS with probability q , or decrease to value dS . What is the value of a call option C on this stock given an exercise price of K ?

We know at the end of period 1, the value of the call option C is either $\max[0, uS - K]$ or $\max[0, dS - K]$. The call option can be represented by a hedging portfolio of the M shares and bonds B that prevents risk less arbitrage. Then the current value of $C = MS + B$.

After one period the value of C is either $C_u = MuS + rB$ or $C_d = MdS + rB$ where r is one plus the risk free rate of return. Solving the equations we find that $M = (C_u - C_d)/(u - d)S$ and $B = (uC_u - dC_d)/(u - d)r$.

As the value of $C = MS + B$ we derive that the value of the call option is:

$$C = \{ C_u[(r - d)/(u - d)] + C_d[(u - r)/(u - d)] \} / r .$$

The unknowns in this formula are the values of S , u , d . In a stock market we know the current price of S . What is the analogous value for an IS investment.

We can imagine that the stock S is a "twin security" for the IS investment. Thus if the present value of the current investment is V , there exists a stock S which accurately reflects the value of the investment. Indeed for convenience we can set $V = S$. If the project is successful its value will increase to V_1 , and if not successful its value will change to V_2 . Then $uS = V_1$ and $dS = V_2$. The value of K is the further investment required to exercise the strategy.

Appendix 2

A Note on Real IT Options and the Productivity

The availability of real IT options highlights the value of information technology investments for positioning the firm to take advantage of uncertainty in addition to increasing productivity through automation. This can explain why organizations continue to invest heavily in information technology despite various macro-economic or firm level studies which show that information technology does not appear to significantly increase economic productivity (e.g Loveman 1988).

Macro-economic or even business level productivity studies do not account for the value of managerial flexibility derived from information technology investments as these studies are focused on the level of outputs given different inputs. Unlike other capital investments in technologies used to increase productivity, information systems investments are often a positioning technology. Thus the effects of IT investments on productivity should perhaps be assessed in comparison to the effects of investing dollars in research and development. Even studies which look for a lagged effect of information technology on productivity may be biased. If many IT investments are unexpired options not exercised during the period of the study, the level of IT investments deployed towards increasing productivity will be over-estimated. This over-estimation of IT investments dedicated to production versus flexibility can negatively bias the outcome of productivity studies. This in turn, can lead to the incorrect conclusion of over-investment in IT systems.

More appropriate assessments of IT investment value will account for the growth realized by the business from projects enabled by information technology. If management adopts an options perspective to IT investments, a preliminary measure of investment success is the return from IT based options and projects divided by the cost of options expired without exercise. This provides a measure for the validity of a firm's IT investment strategy and the capacity to realize value from IT investments.

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¹These numbers are for illustrative purposes only.

²See Cox, Ross and Rubinstein “Option Pricing a Simplified Approach” in the *Handbook of Financial Engineering* (1990) ed. by C. Smith.

³See Cox, Ross and Rubinstein “Option Pricing a Simplified Approach” in the *Handbook of Financial Engineering* (1990) ed. by C. Smith. This closed form of the binomial option pricing formula (replicated for reviewers convenience in Appendix 1) can be applied only to single stage investments. It assumes that project values are in equilibrium after a period. To estimate the value of more complex options it is necessary to employ numerical techniques. Examples are discussed in Brennan and Schwartz [1985], Kulaitilaka [1988] and Pindyck [1988]

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